Data for hygrothermal simulation of Scottish masonry buildings

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Abstract

To facilitate hygrothermal simulation of Scottish traditional masonry, values of relevant material properties have been determined for the following materials: Natural hydraulic lime mortars (NHL2, NHL3.5 and NHL5) and a hot-mixed lime mortar in both the uncarbonated and carbonated states, an earth mortar, three building stones in current production and three building stones used historically but no longer in production. This is the first time such data have been brought together.

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Nomenclature

ρ_0	Dry density (kg/m ³)
ρ_{sat}	Saturated density (kg/m ³)
θ_{sat}	Moisture content at saturation (m ³ /m ³)
θ_{90}	Moisture content at 90% relative humidity (m ³ /m ³)
θ_{MIP}	Porosity by mercury intrusion (m ³ /m ³)
λ_0	Dry thermal conductivity (Wm/K)
λ_{sat}	Saturated thermal conductivity (Wm/K)
μ_{dry}	Dry cup vapour diffusion resistance factor (dimensionless)
μ_{wet}	Wet cup vapour diffusion resistance factor (dimensionless)
W_A	Water absorption coefficient (kg/m ² √sec)

1. Introduction/Background

Traditional solid masonry walls breathe and this moisture transfer ability determines their performance and durability. To prevent accelerated material deterioration, understanding the hygrothermal impacts of building alterations such as retrofitting thermal insulation is critical for structures exposed to significant rain and/or indoor vapour. Hygrothermal simulation software enables designers to assess the impact of insulation retrofits on solid walls and avoid negative effects [1] but information on the hygrothermal properties relevant to Scottish masonry that are needed for simulation is not available. The investigation [2] summarised here aimed to contribute to a dataset of material properties that can be used by designers to ensure that retrofits meet the needs of traditional buildings as well as achieve energy efficiency.

2. Material selection, specimen preparation and testing

Six building stones representative of Scottish masonry were selected. Of those in current production, Hazeldean sandstone, Locharbriggs sandstone and Scottish whinstone were obtained from suppliers. Of those no longer available, Crathes granodiorite (obtained from a roadstone quarry) closely matches Rubislaw granite (which was widely used in Aberdeen), and Craigleith sandstone (Edinburgh) and Giffnock sandstone (Glasgow) were obtained from conservation projects in progress. Mortar was mixed in the laboratory using natural hydraulic lime (NHL2, NHL3.5 and NHL5, St Astier, France) and concrete sand (1:3 by volume). Hot-mixed lime mortar and earth mortar were collected from an active work site in Dunbar, East Lothian. Specimens were cut or cast into 100mm cubes and 90x120x12mm tiles. Lime mortar specimens were carbonated in a controlled environment chamber at 20°C, 60% relative humidity and 600ppm CO₂. All materials were tested singly, not as layered composites.

Density was determined by displacement of water. Thermal conductivity was determined in both the dry and saturated conditions using the Thermtest TLS-100 instrument (Thermtest inc, Fredericton, Canada) and the thermal probe method to ASTM D5334-14 [3]. Water vapour diffusion resistance factor was determined by both dry cup and wet cup methods according to BS EN ISO 12572:2001 [4]. Water absorption coefficient was determined gravimetrically according to BS EN ISO 15148:2002 [5].

Hygroscopic sorption curves were determined according to BS EN ISO 12571:2013 [6], using relative humidities of 33, 53, 75, 85, 93 and 100%. Porosity and pore size distribution were determined by mercury intrusion in a Quantachrome PoreMaster33.

3. Results

Various 1, 3, 4 or 5 specimens were tested for each property (Table 1). The earth mortar disintegrated on contact with water so the saturated density, moisture content at saturation, saturated thermal conductivity and water absorption coefficient were not determined. Additionally, it collapsed under the high intruding mercury pressure needed for the fine pores. The sorption-desorption curves all showed hysteresis with the moisture content on the downcurve higher than that on the upcurve and because their form is the same for all materials, Table 1 shows the moisture contents by volume (θ_0) reached at 90% relative humidity, interpolated from the upcurves but Scottish whinstone is omitted because of an experimental problem. Table 1 also shows the 90% confidence limits, estimated from the variability between measurements on replicate specimens. It should be noted that the interval for water absorption coefficient is given as a percentage of the mean value and that for water vapour diffusion resistance is not constant because the resistance is obtained by dividing the permeability of still air by the permeability of the material.

Table 1. Summary of numerical properties of masonry materials (means of 3, 4^s or 5[^] specimens, or single* determinations).

Material	ρ_0	ρ_{sat}	θ_{sat}	λ_0	λ_{sat}	μ_{dry}	μ_{wet}	W_A	θ_0	θ_{MIP}
90% Confidence interval	± 20	± 20	± 0.004	± 0.75	± 0.75	See below	See below	$\pm 30\%$	± 0.0015	-
Hazeldean sandstone	2275	2300	0.097	1.7	4.0	$37 \pm 5^{\wedge}$	$22 \pm 7^{\wedge}$	0.11	0.0029	0.17*
Locharbriggs sandstone	2200	2275	0.14	1.4	3.4	$30 \pm 3^{\wedge}$	$17 \pm 4^{\wedge}$	0.086	0.015	0.15*
Craighleith sandstone	2450	2500	0.045	1.7	4.2	$120 \pm 60^{\wedge}$	63 ± 10	0.0081	0.013	0.083*
Giffnock sandstone	2200	2300	0.13	1.1	4.2	$37 \pm 5^{\text{s}}$	$18 \pm 4^{\wedge}$	0.073	0.023	0.20*
Crathes granodiorite	2650	2650	0.006	2.1	2.8	$1100 \pm 800^{\wedge}$	$500 \pm 150^{\wedge}$	0.0011	0.0031	0.011*
Scottish whinstone	2925	2925	0.006	1.4	2.4	$1400 \pm 900^{\wedge}$	$600 \pm 200^{\wedge}$	0.00022	-	0.019*
NHL2 mortar uncarbonated	1900	2100	0.20	0.7	1.2	$17 \pm 2^{\text{s}}$	9 ± 2	0.21	0.025	0.19*
NHL2 mortar carbonated	1950	2125	0.18	0.6	1.0	$15 \pm 2^{\text{s}}$	$8 \pm 2^{\text{s}}$	0.26	0.015	0.22*
NHL3.5 mortar uncarb'd	1800	2000	0.18	0.7	1.3	$16 \pm 2^{\text{s}}$	8 ± 2	0.11	0.027	0.24*
NHL3.5 mortar carbonated	1800	2000	0.19	0.7	1.2	$16 \pm 2^{\text{s}}$	$7 \pm 2^{\text{s}}$	0.20	0.015	0.28*
NHL5 mortar uncarbonated	1950	2150	0.20	0.9	1.8	19 ± 2	9 ± 2	0.10	0.031	0.24*
NHL5 mortar carbonated	1975	2175	0.20	0.7	1.3	25 ± 3	11 ± 2	0.32	0.014	0.25*
Hot-mix mortar uncarb'd	1750	1950	0.36	0.2	0.8	$23 \pm 3^{\text{s}}$	$14 \pm 2^{\text{s}}$	0.28	0.026	0.31*
Hot-mix mortar carbonated	1850	2000	0.31	0.2	0.7	$23 \pm 3^{\text{s}}$	$13 \pm 2^{\wedge}$	0.36	0.024	0.30*
Earth mortar	2000	-	-	0.2	-	29 ± 3	$12 \pm 2^{\text{s}}$	-	0.05	-

The general trends within the measured data are consistent: more porous materials are less dense, have lower thermal conductivity, higher water absorption and lower vapour diffusion resistance. The values are generally within the range of values for similar materials, reported by a number of international sources [2].

4. Conclusion

The hygrothermal properties of a range of building stones, natural hydraulic lime mortars and a hot-mixed lime mortar in both the uncarbonated and carbonated states, and an earth mortar, relevant to traditional masonry construction in Scotland are given.

References

- [1] Little, J., Ferraro, C., Arregi, B. (2015). *Assessing risks in insulation retrofits using hygrothermal software tools*. Technical Report 15, Edinburgh, Historic Environment Scotland.
- [2] Banfill, P.F.G. (2021). *Hygrothermal simulation of building performance: data for Scottish masonry materials*. Materials and Structures, in communication.
- [3] ASTM. (2014). *Standard test method for determination of thermal conductivity of soil and soft rock by thermal needle probe procedure*. D5334-14, West Conshohocken, USA, ASTM International.
- [4] BSI. (2001). *Hygrothermal performance of building materials and products – Determination of water vapour transmission properties*. BS EN ISO 12572:2001 London, British Standards Institution.
- [5] BSI. (2002). *Hygrothermal performance of building materials and products – Determination of water absorption coefficient by partial immersion*. BS EN ISO 15148:2002 London, British Standards Institution.
- [6] BSI. (2013). *Hygrothermal performance of building materials and products – Determination of hygroscopic sorption properties*. BS EN ISO 12571:2013 London, British Standards Institution.